Method statement

Life Cycle Assessment (LCA)

A Life Cycle Assessment (LCA) aims to provide a comprehensive analysis of the environmental impacts across every phase of a product's lifecycle. For vehicles, the present LCA calculator considers the direct and indirect impacts of vehicle manufacturing, fuel production and distribution, and the use of the vehicle.

System boundaries

This assessment focuses on the GHG emissions associated with passenger light-duty vehicles (small, medium, large, pickup, SUV) of various powertrains – battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and internal combustion engine vehicles (ICEV). The lifecycle emissions are split into the following categories:

Vehicle cycle

- Vehicle manufacturing
- Battery manufacturing

Fuel cycle

- Fuel production (well-to-tank)
- Fuel consumption (tank-to-wheel)

Across the two categories, we consider emissions that are produced during the manufacturing and extraction of the materials and fuel, as well as emissions related to transport of materials or fuels, and to electricity or heat generation. Emissions related to material and battery manufacturing consider the effects of recycling to a degree, in line with current market trends and implemented policies. The aim of the calculator is to provide a comprehensive but easy-to-understand way to compare emissions between countries and across car types. The calculator also allows the user to carry out a series of sensitivity analyses according to their specific needs, by changing a number of parameters that influence overall lifecycle emissions. There are other tools available that go into more detail on model-specific emissions, such as carculator and carboncounter.

Vehicle manufacturing

Vehicle manufacturing emissions are those associated with the production of materials and components (excluding the BEV and PHEV battery) and vehicle assembly. For the production of steel and aluminium, the default assumptions in the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model[1] are adjusted to better reflect the volume-weighted average emissions intensity of mining and material production, based on IEA modelling of these supply chains. This is to compensate for the US focus of GREET. For the other materials, we use GREET assumptions, altering the electricity and/or fossil fuel emissions to use a global weighted average of CO_2 equivalent (CO_2-eq) emitted during electricity generation and fossil fuel usage.

The mass of the vehicle varies by size and powertrain, and is derived from S&P Global Mobility and EV Volumes. The material intensity is based on the share of vehicle mass for each material (excluding the EV battery) as provided by the GREET tool. The material composition varies by powertrain (BEV, PHEV and ICEV), independent of fuel type. For the ICE vehicles, emissions related to the lead-acid battery are from GREET and assumed (independent of vehicle size) to be 0.04 t CO_2-eq/vehicle.

Average mass in kilogrammes by vehicle powertrain and size, excluding the battery

Size	BEV	PHEV	ICEV
Large	1 380	1 840	1 870
Medium	1 250	1 600	1 420
Small	840	-	1 030
Pickup	2 520	-	1 870
SUV	1 530	2 010	1 740

Notes: BEV and PHEV masses are estimated from EV Volumes from sales in 2022; ICEV masses are estimated using S&P Global Mobility database from 2021 sales. Small cars include A and B segments. Medium cars include C and D segments and A segments with SUV body type. Large cars include E and F segments, multi-purpose vehicles and B segments with SUV body type. SUV category encompasses segments C to F with SUV body type. The pickup category includes segments D and E with pickup body type.

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[1] GREET is a tool that assesses lifecycle energy use and emissions and other impacts. It was developed and is managed by the US Department of Energy's Argonne National Laboratory. Different versions of the model are used to support regulations such as California's Clean Fuel Standard.

Material composition by powertrain, excluding the EV battery

Material	BEV	PHEV	ICEV
Steel	66%	61%	63%
Aluminium	13%	14%	13%
Copper	4%	6%	2%
Glass	2%	2%	2%
Plastic	12%	13%	16%
Rubber	3%	3%	4%

Source: GREET (2022).

Battery manufacturing

Battery manufacturing emissions include those emitted during minerals extraction, refining, the production of the cathode (e.g. nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), nickel cobalt aluminium oxide (NCA)) and the anode (graphite) active material, electrodes and cell processing, and battery pack assembly. The materials requirement and emission intensity (except for electrode and cells manufacturing) were calculated using a combination of GREET and IEA data, with the latter preferred where available. Electrodes and cell manufacturing emissions were calculated by combining data reported by Dai et al. and IEA analysis. Battery production emissions are calculated as a weighted global average. As such, the actual emissions associated with batteries produced in a given country could therefore have a lesser, or greater, impact. Today, around 15% of overall battery emissions are associated with battery production and assembly for NMC or NCA chemistries; this share is over 40% in the case of LFP batteries. The lower energy density of LFP at the material level leads to greater energy requirements for the battery manufacturing step, because lower energy density implies the need to produce more cathodes, anodes, and cells (by mass) in order to produce a given battery capacity (kWh). The ratio between the energy required for producing LFP batteries compared to NMC used in this tool was calculated by Degen et al.

The battery size (in kWh and kg) is calculated as a function of the vehicle range, fuel economy, and battery energy density. Battery cell energy density is estimated based on the 2022 sales-weighted average cell energy density reported by EV Volumes. Conversion factors from Frith et al. are then used to estimate battery pack energy density. The battery pack carbon intensity and energy density used in this tool are about 90 kg of CO_2-eq per kWh and 150 Wh/kg, respectively, and they reflect the 2022 sales-weighted mix of battery cathode chemistries, rather than one single chemistry. The choice of the chemistry, however, does have an impact, with LFP batteries having about two-thirds of the emissions of high-nickel chemistries.[2]

Depending on the temperature, operation and charging mode, the state-of-health of the EV battery deteriorates over time. The LCA tool therefore includes an option for battery replacement, which assumes some process and technology improvements: reduced CO_2 intensity of electricity and heating, 30% increased energy density, and 20% of the cathode active material sourced through recycling. If the battery replacement option is selected, this is assumed to happen after 10 years of a vehicle's lifetime. Standards have been introduced to improve battery lifetime, and the minimum durability standards drafted by the United Nations Economic Commission for Europe have been adopted by the European Union, United States, China, India, Japan and other major producers. These standards state that after 8 years or 160 000 km (whichever comes first) the battery must hold at least 70% of the energy it could when new, meaning a maximum reduction of range of 30% after 8 years (or 160 000 km).

In this tool, battery manufacturing emissions do not take into account emissions associated with the transport of materials and battery end-of-life activities. The battery replacement considers the emissions related to the recycling process to source 20% of the cathode active material through recycling. Emissions related to the recycling process are, however, more than offset by the reduction in emissions resulting from avoided demand for such materials, thus reducing demand for mining and primary materials refining. Battery second life was not considered due to a lack of reliable data, which is a consequence of the currently limited number of EVs having reached end-of-life.

Fuel production (well-to-tank)

Well-to-tank emissions are generated during the production and transportation of the fuel/energy.

Gasoline and diesel

With respect to fossil fuel production, emissions are produced from the energy consumed when extracting and refining crude oil into products including gasoline and diesel (which generally requires the combustion of fossil fuels themselves). Flaring, as well as fugitive and vented methane (a powerful GHG), also contribute to the overall emissions, with this contribution varying substantially by region. Differences in the ease of extraction, the amount of processing required, and local regulations (including differences in adherence) mean that the well-to-tank emissions for gasoline

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[2] For more information please refer to the IEA Global EV Outlook 2024.

and diesel vary by region. The IEA aggregates these effects, as well as accounting for international trade, to give regional weighted averages.

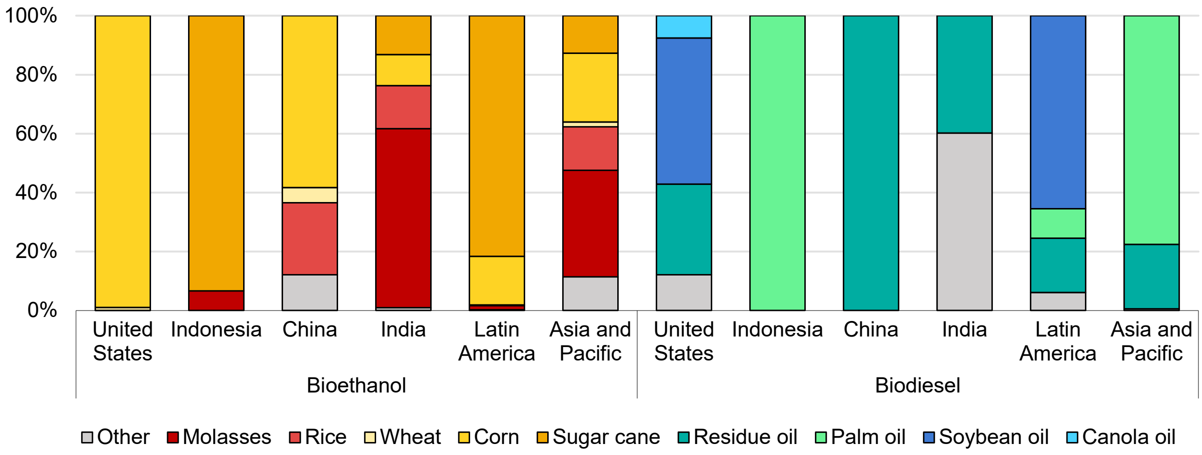
Biofuels

Biofuel emissions include agricultural operations (sowing, cultivation, harvesting), feedstock transport, industrial processing and transport of the biofuel. Biofuel emissions vary substantially depending on the feedstock and biofuel production process. Direct land use change, where land-use is modified for biofuel production, is not considered in this analysis. In the case of residue-based biofuels, the feedstock production stage (e.g. agriculture) is not included. Residue-based biofuels generally have lower carbon intensities.

This analysis uses average lifecycle GHG intensities for ethanol and biodiesel in each country based on the evolution of each country's feedstock mix and production pathways over time. The lifecycle GHG intensities are based on a detailed life cycle assessment of 16 different feedstocks, and 6 biofuel production processes. The underlying data is taken from GREET and IEA sources. A more detailed discussion of the methodology is available in the Global Fuel Economy Initiative.

The assumed feedstock mix for each biofuel type for each country in 2023 is illustrated in the figure below. This mix changes over time based on IEA estimates of biofuel policy, capacity additions and technology changes.

Feedstock composition by biofuel per country or region, 2023



Source: IEA (2023), Renewables 2023.

This assessment does not include indirect land use change (ILUC) emissions factors since there remains considerable uncertainty in ILUC estimates, and no common approach for its inclusion in existing regulations. Including ILUC emissions factors can significantly increase the carbon intensity of some biofuel pathways. A number of jurisdictions do not quantify ILUC emissions, but do address the issue through a qualitative risk-based policy approach.

At the time of writing, the IEA is supporting G20 activities under the Brazilian Presidency around challenges and possible solutions in carbon accounting methods and sustainability frameworks of biofuels. The present LCA tool will be updated in future to include additional country information and possible new features to reflect IEA work that is currently ongoing.

Electricity

In this LCA tool the IEA Life Cycle Upstream Emission Factors database and values for direct emissions from IEA modelling are used to quantify total emissions from electricity. They provide a weighted average of the various fuels/sources used to generate the electricity required. The limitation of such an approach is that it does not capture the potentially complex interactions between the behaviour of the vehicle owner/operator and the operation of the electrical grid. One aim of smart charging, for example, is to maximise the share of renewable energy used when charging. Using another IEA tool, the Electric Vehicle Charging and Grid Integration Tool, users are able to simulate such interactions at a high level and understand how EV charging can be sustainably integrated into the system.

Fuel consumption (tank-to-wheel)

Akin to direct emissions, tank-to-wheel emissions are generated during the operation of the vehicle.

Gasoline and Diesel

The tailpipe/exhaust emissions of gasoline and diesel are assumed to be approximately 2.3 kg and 2.7 kg of CO_2 per litre of fuel, respectively.

Biofuels

The tank-to-wheel emissions from biofuel combustion are assumed to be carbon neutral (i.e. 0 kg CO_2 per litre of fuel) as the biogenic carbon contained in the fuel is sequestered from the atmosphere during the growth phase of relevant biomass feedstocks.

Electricity

As electricity is used to charge the battery, which then powers the vehicle, all of the emissions of battery electric vehicles occur in the well-to-tank phase.

Other considerations

Plug-in hybrid electric vehicles

Plug-in hybrid electric vehicles (PHEVs) differ from standard hybrid electric vehicles in that they have a larger battery, typically allowing for an all-electric range of around 60 km, and the ability to charge that battery from an external source. In general, the car is programmed to balance use of the battery and engine to minimise fuel consumption.

The utility factor is the distance covered in electric mode as a share of the total distance driven and is crucial in estimating the fuel cycle emissions of PHEVs, as it determines the volumes of electricity and petrol consumed. Typical values for private cars are around 40%, though this is highly dependent on individual behaviour and the use case. Short-distance urban driving is associated with higher utility factors, and long-distance highway driving with lower utility factors. In this tool, the default value is 40%, but users can adjust this between 0% and 70%, to see the impact.

Biofuel blending limits

Tool users can select different biofuel blending levels for each country. The default value is the average biofuel share in each country as of 2023 on a volume basis. However, users can select higher and lower blending levels to view the impact on GHG intensity. Higher blending levels are set to match blending options in each country based on existing policies and vehicle technology availability. For instance, India is targeting 20% ethanol blending and so the tool includes a 20% blend rate option. In the United States, there are over 4 000 E85 blending stations, and so the tool includes an 85% ethanol blend option.

Fuel economy

Central estimates for fuel economy by powertrain are based on research done as part of the IEA Global Fuel Economy Initiative 2021 and while maintaining the IEA road database. These central estimates for each region were scaled to provide a value for each vehicle size based on analysis of the IEA road database as well as subsequent online and internal research. The highest and lowest value globally for each vehicle size provides the upper and lower limits that the user can select between.

Vehicle size and shape, mass, specific engine/motor performance, driver behaviour, and local weather conditions, among other factors, greatly affect vehicle fuel economy. A wide range of possible values are therefore available when selecting the fuel economy within the tool. The existence of this range highlights the benefits of a fuel-efficient vehicle, and, conversely, the additional impact of vehicles with higher fuel consumption.

An additional 2% energy consumption has been applied to EV fuel economy to account for losses not included in Worldwide Harmonised Light Vehicle Test Procedure (WLTP) figures, such as additional losses that will occur in equipment between the distribution grid and the charger. The exact figure depends on charging power and local voltage levels, therefore 2% is a global weighted average value.

Fuel economy values are determined based on analysis of various third-party databases reporting fuel consumption on different driving duty cycles (New European Driving Cycle (NEDC), Environmental Protection Agency (EPA) 5-cycle procedure, Japan JC08 and the Worldwide Harmonized Light Vehicles Test Cycle (WLTC)) across the regional coverage of the LCA tool. To ensure consistency, all fuel economy values are converted back to their WLTC equivalent using conversion factors either taken from a simulation study found in literature or derived from the analysis of fuel economy datasets that report measurements for both WLTC and other driving cycles. Despite representing real-world conditions more accurately than the NEDC, the WLTC still tends to underestimate fuel economy, due to differences in driving behaviour, regional climate, and approval test optimisation. We therefore assume a correction factor of 1.1 to compensate for this underestimation.

Improvements in well-to-tank emissions

The emissions associated with fossil fuels, biofuels and electricity production will decline over time due to technology improvements, greater shares of renewable energy and greater process efficiency. In this tool the user can switch between two pathways for these emissions, the IEA Stated Policies Scenario (STEPS) and the Net Zero Emissions by 2050 Scenario (NZE Scenario). These scenarios are detailed further in the IEA's long-term outlook publications, such as the World Energy Outlook (WEO) and Energy Technology Perspectives (ETP).

It is anticipated that improvements in exploration and refining, particularly with respect to reduced methane emissions, will reduce the lifecycle emissions of fossil fuels, including petrol and diesel. This reduction in fossil fuel emissions will also reduce the carbon footprint of the electricity generated from fossil fuels, albeit with a far smaller impact than increasing shares of low-carbon generation. With respect to biofuels, improved fertiliser practices, a greater share of biofuels from waste and residues, and improvements in production practices will reduce the associated emissions.